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Weapon Zeroing with the Laser Marksmanship Training System (LMTS)

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August 1999

U.S. Army Research Institute for the Behavioral and Social Sciences

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14. ABSTRACT *(Maximum 200 words)*: This research examined the Laser Marksmanship Training System's (LMTS's) capability to establish a valid weapon (i.e., M16A2 rifle) battlesight zero. A multi-phased approach was used to (a) examine the validity of an LMTS-established zero under live-fire conditions, (b) reexamine this validity using an alternative (presumably more accurate), manufacturer-recommended, LMTS zero calibration procedure, and (c) assess the degree of correspondence between LMTS point of aim and live bullet strike location under stabilized weapon conditions. Only 27% of LMTS-zeroed weapons were found to have confirmable live-fire zeroes, with no benefit resulting from use of the alternative zero calibration procedure. LMTS's aiming point also did not correspond to bullet strike location. Weapon quality was suggested to be a major factor contributing to this lack of correspondence. These findings indicate that an LMTS-established weapon zero may not always correspond to, and thus should not be substituted for, a live-fire-established weapon zero. Consequently, soldiers should not attempt record fire qualification with an LMTS-zeroed weapon without first confirming zero with live ammunition. Range time and ammunition savings resulting from the use of LMTS-zeroed weapons should be modest at best, given the relatively low percentage of LMTS-zeroed weapons found to have valid zeroes. Additional research is underway to examine the feasibility of using LMTS for marksmanship training and evaluation.

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Weapon Zeroing with the Laser Marksmanship Training System (LMTS)

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FOREWORD

The United States Army Reserve (USAR) is looking for more effective and resource-efficient ways to train and evaluate rifle marksmanship through the use of training devices. To this end, and at the request of the Deputy Commanding General of the U.S. Army Reserve Command (USARC), the U.S. Army Research Institute's Reserve Component Training Research Unit (ARI-RCTRU) has been working in partnership with USARC's 84th Institutional Training Division (DIVIT) and Small Arms Training Team (SATT) to develop and evaluate a device-oriented rifle marksmanship sustainment training program for use at home station (i.e., reserve centers) on drill weekends. The common goal of this cooperative effort is to ensure the to-be-developed training program is capable of producing marksmanship proficiency levels that meet, or exceed, unit readiness requirements while minimizing the resources expended to do so.

Although training program development is still in its formative stage, initial plans call for use of the Laser Marksmanship Training System (LMTS) to achieve this goal. Before a final decision is made to incorporate LMTS into the envisioned program, however, several questions must be answered about the capabilities of the device per se as well as its ability to support effective and efficient training. This report answers the question of whether or not a weapon zero established with LMTS corresponds to, and thus can be substituted for, a live-fire-established zero, and thereby minimize the range time and ammunition required for yearly rifle marksmanship qualification firing in the USAR.

This research was conducted by the ARI-RCTRU, whose mission is to improve the effectiveness and efficiency of Reserve Component (RC) training through use of the latest in training technology. This research is supported under Work Package 207, "Maximizing Payoff of Reserve Training," of ARI's Science and Technology Program for Fiscal Year 1999.

This research was sponsored by USARC under a continuing Memorandum of Understanding initially signed 12 June 1985. Findings have been presented to Director, USARC; and DCSOPS, USAR 84th DIVIT.

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WEAPON ZEROING WITH THE LASER MARKSMANSHIP TRAINING SYSTEM (LMTS)

EXECUTIVE SUMMARY

Research Requirement:

Determine the validity of an LMTS-established battlesight zero for the M16A2 rifle.

Procedure:

A multi-phased research approach was used to (a) examine the validity of an LMTS-established zero under live-fire conditions, (b) reexamine this validity using an alternative (presumably more accurate), manufacturer-recommended, LMTS zero calibration procedure, and (c) assess the degree of correspondence between LMTS point of aim and live bullet strike location under stabilized weapon conditions.

Findings:

Only 27% of LMTS-zeroed weapons were found to have confirmable live-fire zeroes, with no benefit resulting from use of the alternative zero calibration procedure. LMTS's aiming point also did not correspond to bullet strike location. Weapon quality was suggested to be a major factor contributing to this lack of correspondence.

Use of Findings:

An LMTS-established weapon zero may not always correspond to, and thus should not be substituted for, a live-fire-established weapon zero. Consequently, soldiers should not attempt record fire qualification with an LMTS-zeroed weapon without first confirming zero with live ammunition. Range time and ammunition savings resulting from the use of LMTS-zeroed weapons should be modest at best, given the relatively low percentage of LMTS-zeroed weapons found to have live-fire confirmable zeroes. Additional research is underway to examine the feasibility of using LMTS for marksmanship training and evaluation.

WEAPON ZEROING WITH THE LASER MARKSMANSHIP TRAINING SYSTEM (LMTS)

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Weapon Zeroing with the Laser Marksmanship Training System (LMTS)[1]

Introduction

The combination of budget cutbacks, escalating ammunition costs, reduced access to live-fire ranges, reports of substandard rifle marksmanship proficiency (San Miguel, 1998), and ever-present training time constraints has prompted the USAR to search for more effective and resource-efficient ways to train and evaluate marksmanship through the use of training devices. To this end, the U.S. Army Research Institute's Reserve Component Training Research Unit (ARI-RCTRU) has been working in partnership with the U.S. Army Reserve Command's (USARC's) 84th Institutional Training Division (DIVIT) and Small Arms Training Team (SATT) to develop and evaluate a device-based rifle marksmanship sustainment training program for USAR soldier use at home station (i.e., reserve centers) on drill weekends (Plewes, 1997, Oct 9).

Under this partnership, SATT is responsible for development of the training program's course of instruction (COI), ARI-RCTRU is responsible for designing the research needed for formative and final COI development and effectiveness/efficiency evaluation, and the 84th DIVIT is USARC's designated executive agent responsible for overall project coordination and conduct. The common goal of this cooperative effort is to ensure that the to-be-developed sustainment training program will produce USAR soldier rifle marksmanship proficiency levels that meet, or exceed, unit readiness requirements while minimizing the resources (e.g., time, ammunition) needed to do so (Plewes, 1997, Nov 24).

Although training program development is still in its formative stage, plans call for device use to (a) identify which soldiers are in need of sustainment training, (b) reinforce marksmanship fundamentals (i.e., steady position, aiming, breath control, and trigger squeeze) and weapon battlesight zeroing procedures, (c) enable practice record fire qualification firing with electronic targets, and, if feasible, (d) replace live-fire qualification with device-based qualification when live-fire ranges are unavailable.

Based on a relative capabilities analysis of candidate training devices, (Memorandum For Record, 1997, Dec 14) USARC has concluded that the Laser Marksmanship Training System (LMTS) (BeamHit, 1999) is best suited to support the above usage plan. LMTS is an indoor, laser-emitting device with which targets can be engaged using actual weapons without the use of live ammunition. Its major components include a laser transmitter, a mandrel to which the transmitter is attached/aligned, a variety of laser sensitive targets, and a laptop computer with optional printer (Figure 1). One end of the mandrel holds the laser transmitter and the other end slips into the barrel of the weapon, in this case the M16A2 rifle. Vibrations from the rifle's firing mechanism activate the laser when the weapon is dry fired and the location of the emitted beam is "picked up" by the laser-sensitive target(s) (Dulin, 1999) and then recorded and temporarily stored on the computer for future printout.

[1] Because of their equal contribution to this report, authors are listed in alphabetical order.

Unlike other marksmanship training devices in the Army's inventory (e.g., Multipurpose Arcade Combat Simulator [MACS] [e.g., Hunt, Broom, Green, Crawford, & Martere, 1987; Schroeder, 1984)], Weaponeer [Schendel, 1985; Schendel, Heller, Finley, & Hawley, 1985], and Engagement Skills Trainer [EST] [Scholtes & Stapp, 1994]), LMTS allows soldiers to train with their own weapons with the laser transmitter and mandrel attached as a barrel insert. The device is also relatively inexpensive and, consequently, could be fielded in sufficient quantities to most, if not all, reserve center locations. These reasons, coupled with the device's ease of setup and operation, have prompted USARC's decision to consider LMTS for use in the envisioned marksmanship sustainment training program.

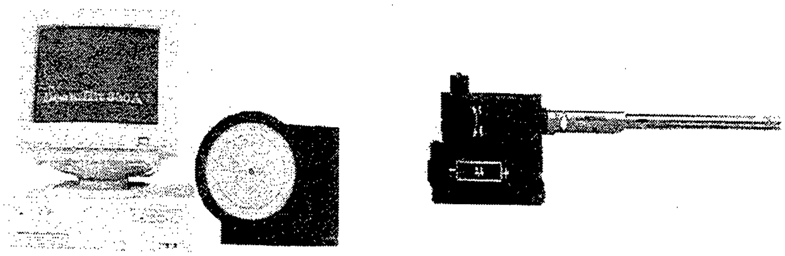

Figure 1. LMTS computer/monitor, sample electronic target, and laser transmitter with attached mandrel.

Before a final decision to incorporate LMTS into this program can be made, however, several questions must be answered about the capabilities of the device per se as well as its ability to support effective and efficient training. One question to be answered about the LMTS itself, and the focus of this report, is whether or not the device can be used to establish a weapon zero that will support yearly qualification firing. Given that current plans call for the new COI to include LMTS-based weapon zeroing practice, it would be beneficial to know from a resource efficiency standpoint if a potential byproduct of this practice is a weapon zero that does not require live-fire confirmation. If so, an LMTS-established zero could take the place of a live-fire-established zero and the time and ammunition usually required to live-fire zero before qualification firing could be eliminated.

USAR units typically devote one drill weekend each year to marksmanship training and qualification firing, with most of the latter's time taken up by the zeroing process (i.e., applying marksmanship fundamentals to establish a tight shot group [grouping] and then adjusting the fire control system [sights] to ensure that weapons fire where aimed [zeroing] (Headquarters, Department of the Army, 1989). If these weapons could be zeroed with LMTS during training at the reserve center and then carried to the range without the need for follow-up live-fire confirmation, some range time could be freed up for conduct of other mission-related activities during drill. This report describes the results of a three-phased research effort designed to examine the feasibility of this notion.

Phase 1

The purpose of this initial phase was to determine the validity of an LMTS-established zero under live-fire conditions. In general, the laser transmitter was attached to, and aligned with, the mandrel before insertion into the weapon muzzle to ensure consistent laser beam impact. One set of weapons was then zeroed using LMTS with the transmitter/mandrel inserted in the muzzle while another set was zeroed with live ammunition. All weapons were then fired with live ammunition to (1) determine the validity of the LMTS-established weapon zero, and (2) compare the confirmation rate achieved under the two zeroing procedures, with the live-fire-to-live-fire confirmation rate used as the standard against which to judge the relative success of the LMTS-based zeroing process.

Method

Participant

One All-Reserve Rifle Team marksman from SATT participated as the shooter. He zeroed all weapons using both LMTS and live ammunition and then performed all zero confirmation firing on the range.

Procedure

As shown in Table 1, the shooter zeroed a total of 50 weapons (M16A2 rifles); 1-25 with live ammunition (M193) fired outdoors on a 25m live-fire range (Range 21) at Fort McClellan, AL, and 26-50 with LMTS indoors at the SATT reserve center. To establish a live-fire zero, the shooter fired a minimum of six rounds to establish an acceptable shot group, adjusted the sights as needed, and then fired six more live rounds at an Army standard 300m M16A2 zeroing target (Figure 2). This process was continued until five of six rounds were placed inside, or touching the border, of the 4cm circle of the target, at which point a weapon was considered zeroed (Headquarters, Department of the Army, 1989). Establishment of an LMTS-based zero involved use of the device's laser-sensitive, bulls-eye zeroing target (see Figure 3) to record the impact location of laser rounds. The shooter fired a minimum of three laser rounds for which the computer calculated the geometric center (centroid) of impact and plotted it on the computer-generated, bulls-eye target displayed on the monitor. Based on the centroid location, the shooter adjusted sights as needed and continued shooting until five of six shots fell inside the target's 8th-ring, corresponding in size to the 4cm circle of the Army standard M16A2 zeroing target. The weapon was then considered zeroed.

Table 1
Phase 1 Data Collection Design

Weapon	Establish Zero	Confirm Zero
1-25	Live-Fire Range	Live-Fire Range
26-50	LMTS	Live-Fire Range

Zero confirmation firing was then conducted for both sets of rifles on the outdoor range (on the same day) using M193 ammunition, Army standard M16A2 zeroing targets, and application of the above described Army zeroing standard (Headquarters, Department of the Army, 1989).

Weapons in the two groups were alternated until all 50 were fired for zero confirmation. Both LMTS and live firing, in this and in all subsequent phases of the research, were conducted from the prone-supported position. Range firing occurred under clear skies and temperatures in the 70s.

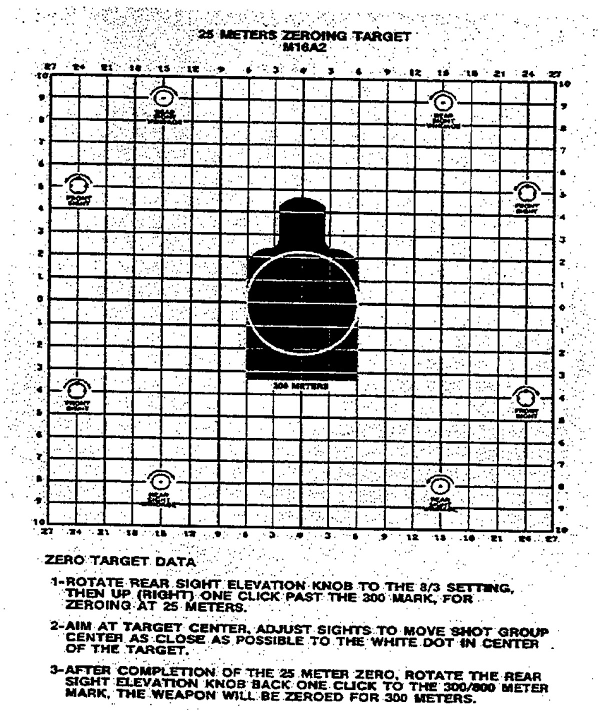

Figure 2. The 300m M16A2 rifle zeroing target.

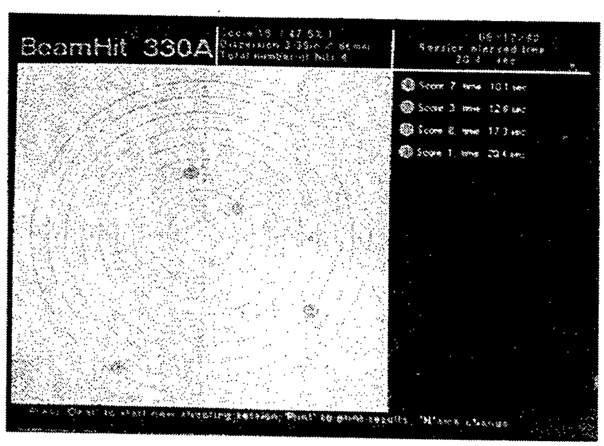

Figure 3. LMTS bulls-eye zeroing target.

The dependent measures of interest were the number/percentage of weapons with confirmed zeroes, and how many of the six live rounds fired per weapon landed "on paper" as well as within the target's zeroing circle during the confirmation process. The rejection region for all statistical analyses was .05.

Results

Zero was confirmed on the live-fire range for 8 (32%) of the 25 LMTS-zeroed weapons and for 20 (80%) of the 25 live-fire zeroed weapons, with the latter percentage being significantly greater than the former ($z = 6.00$) (Spence, Underwood, Duncan, & Cotton, 1968). All zeroing rounds fired with each group of weapons were found to land on paper. A greater mean number of rounds landed within the zero target circle for live-fire zeroed weapons (5.3), however, than for LMTS-zeroed weapons (2.3), $F(1,48) = 26.1$. Given that we were anticipating similar zero confirmation rates and zeroing target circle hits for the two weapon groups, the findings for LMTS-zeroed weapons were unexpected.

Phase 2

A possible explanation for the lower LMTS-based zero confirmation rate in Phase 1 is that the laser beam calibration procedure could have resulted in an inaccurate aiming point because of bias associated with positioning of the laser transmitter mandrel in the muzzle of the weapon. In Phase 1, the mandrel was inserted into the barrel, three laser rounds were fired at the target, and then these laser impact points were used to calculate a laser centroid, using a mathematical centering algorithm programmed into the device's computer. This centroid was then used as the aiming point against which to adjust weapon sights during zeroing.

In this phase, we reexamined the validity of an LMTS-established zero using an alternative laser beam calibration procedure recommended by the device's manufacturer. Under this procedure, the transmitter mandrel was positioned (rotated) at 0, 90, 180, and 270 degrees with three laser rounds fired at each location. The same mathematical centering algorithm was then used to calculate the laser centroid, and subsequent sight adjustments using this (presumably more stable and accurate) aiming point were made during zeroing. We thought that this more exhaustive calibration procedure would help to stabilize laser centroids, reduce discrepancies between the calculated laser aiming point and subsequent bullet strike location, and consequently produce a higher rate of LMTS to live-fire zero correspondence.

Method

Participant

One retired military expert-rated marksman from the Army Marksmanship Unit, Fort Benning, GA, participated as the shooter. He performed the actions required to zero all weapons with the LMTS and to test the validity of this zero with live ammunition.

Procedure

The shooter zeroed five "rack" grade M16A2 rifles (i.e., those typically issued for qualification firing) with LMTS using the manufacturer-recommended rotational procedure. After each weapon was zeroed, the shooter then fired a total of six live rounds (M193) at an M16A2 zeroing target placed 25m downrange to test the validity of the LMTS-established zero. We then measured the number/percentage of weapons with a confirmed zero, and how many of the six live rounds fired per weapon landed on paper as well as within the target's 4cm zeroing circle. As before, each weapon was judged to be zeroed if five out of the six live rounds fired were found to land within, or on the border of, this circle.

Results

The LMTS-established zero failed to be confirmed with live ammunition on any of the five weapons fired (0%). All live rounds landed on paper with an average of 2.0 landing within the zeroing target circle, with the number of live round circle hits in this phase being comparable to that (2.3) obtained with the LMTS zeroed weapons in Phase 1, $F(1,28) < 1$, but significantly less, $F(1,28) = 27.1$, than that (5.3) obtained with live-fire zeroed weapons in Phase 1. Thus, the laser beam rotational calibration procedure did not improve the LMTS-based zero confirmation rate or the associated number of circle hits.

A repeat of the above procedure with 10 "match" grade weapons (i.e., those typically used for competition firing) resulted in 6 out of 10 (60%) confirmed zeroes--a confirmation rate less than the expected (80%) confirmation rate established in Phase 1 ($z = 2.5$). The average number of live round circle hits found for LMTS-zeroed match grade weapons (4.4), however, did not differ significantly from that (5.3) found for Phase 1 live-fire zeroed rack grade weapons, $F(1,33) = 2.77$. Of course, match grade weapons are not ordinarily issued for training or qualification purposes, but the difference in confirmation rate found for the two grades of weapons suggests that weapon quality may be a major factor contributing to the low zero confirmation rate obtained in these first two phases of our research.

Phase 3

To examine further why previous attempts to confirm an LMTS-established zero were unsuccessful, we assessed the correspondence between LMTS's laser beam aiming point (i.e., that against which sight adjustments are made during zeroing) and bullet strike location obtained with live ammunition. On the one hand, if laser beam aiming point and bullet strike location are found to correspond, then the former could be claimed to represent an accurate reference point against which to weapon zero. On the other hand, if the two locations are not found to correspond, then it could be argued that the relatively low LMTS zero confirmation rates in Phases 1 and 2 could be caused (at least in part) by an incorrect LMTS laser beam aiming point used for weapon zeroing. To test the degree of correspondence, we eliminated shooter variability by stabilizing the weapons during both LMTS and live firing. With weapons stabilized, and all shooter effects thereby removed from the situation, we expected that the laser beam aiming point should be identical (within ammunition dispersion tolerances) to bullet strike location.

Method

Procedure

A cradle (Figure 4) was used to stabilize five rack grade weapons to which each of five LMTS laser transmitters was affixed one at a time once each transmitter was aligned with the mandrel to ensure consistent laser beam impact. For Weapon 1, five targets (one for each laser transmitter) were stapled together front to back to form a laser target group of five targets. Laser Transmitter 1 was then used to fire four laser rounds (one at each of the four rotational locations: 0, 90, 180, and 270 degrees) at the top M16A2 zeroing target and the geometric center (the laser centroid [i.e., aiming point]) was calculated using the same mathematical centering algorithm described in Phase 2. Laser Transmitters 2-5 were then in turn inserted into Weapon 1 and their centroids calculated in a similar fashion on their respective targets. After removing the last laser transmitter from Weapon 1, and without moving the weapon or the associated target group, three live rounds were fired at the first target group. The live round shot group centroid was then calculated using the centering algorithm described above. This procedure was repeated until all weapons had been live fired. The result was a total of 15 live rounds fired, three at each of the five target groups.

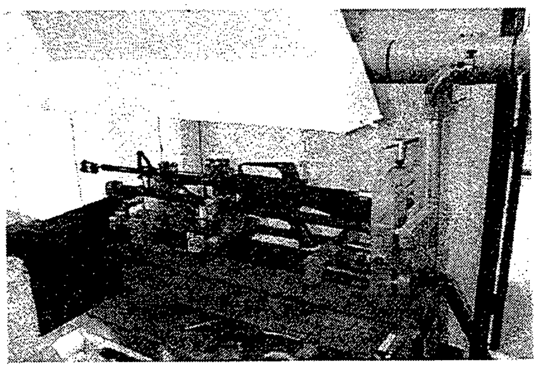

Figure 4. Weapon stabilization cradle.

We then measured the distance between each laser beam centroid and the centroid of the live round shot group, as well as that between laser centroids and each individual bullet hole. Centroid-to-centroid measurements produced 25 data points (5 rifles by 5 lasers) and laser-centroid-to-individual-bullet-hole measurements produced 75 data points (25 targets by 3 bullet holes per target). As a reference point, we also calculated bullet strike variability on each target (maximum distance between the center points of the two most widely separated bullets), and reasoned that in order to conclude that laser and bullet centroids are identical, the distance between bullet and laser centroids should not exceed bullet strike variability.

Results

The mean bullet strike variability of the live-round shot groups was 21.2mm (SD = 8.8mm; n = 5). The mean distance from laser centroids to bullet centroids was 42.9mm (SD = 34.4; n = 25), and the mean distance from laser centroids to individual bullet holes was 45.4mm (SD = 33.5; n = 75). Both centroid-to-centroid distances and centroid-to-individual-bullet-hole distances were significantly greater than the observed live ammunition dispersion/variability benchmark (i.e., 21.2mm), $t(24) = 3.09$, and $t(74) = 6.26$, respectively (Leitner, 1972, pp. 162-184). Although lasers and bullets both produced their own distinct clusters, these clusters were typically at different locations on the targets, notwithstanding the fact that all rifles were immobilized during both laser and live-fire stages of data collection. Laser impact location and bullet impact location were separated, on average, by more than 40mm. This would explain, at least in part, the relatively low zero confirmation rates found in Phases 1 and 2. In essence, weapon sights were adjusted during zeroing to coincide with an errant aiming point provided by LMTS.

An analysis of variance conducted on LMTS laser centroids revealed that individual lasers had no effect on either the vertical or horizontal component of target strike location, $F(4,20), p < 1$, and $F(4,20) < 1$, respectively. Individual lasers also had no effect, $F(4,20) < 1$, on the distance between laser and bullet centroids. When similar analyses were conducted using individual weapons as the variable of interest, however, significant results were obtained on vertical and horizontal impact components, $F(4,20) = 10.7$, and $F(4,20) = 11.0$, respectively, and on distances between laser and bullet centroids, $F(4,20) = 46.7$. Substantial variability existed, therefore, not only between rack grade and match grade weapons (see Phase 2), but also among the individual rack grade weapons themselves.

General Discussion

The objective of this investigation was to determine if an LMTS-established zero corresponds to, and thus can be substituted for, a live-fire-established zero. Our findings indicate that a precise one-to-one correspondence does not exist, and lead to the recommendation that USAR soldiers should not attempt record fire qualification with an LMTS-zeroed weapon without first confirming this zero with live ammunition.

Nonetheless, our findings do suggest a couple of reasons why at least modest range time and ammunition savings are likely to result from the firing of LMTS-zeroed weapons. First, the combined results of Phases 1 and 2 revealed that around 27% (i.e., 8 of 30 rack grade weapons) of these weapons indeed had confirmable zeroes and, therefore, would have required no additional sight adjustments prior to qualification firing. For this relatively small percentage of weapons, live-fire grouping would still be required to demonstrate acceptable shot group patterns but subsequent sight adjustments and the additional time and rounds required to confirm zero could be eliminated, thereby streamlining the overall qualification firing process. Of course, a portion of the time, but not the ammunition, saved on the range will be offset by prezeroing weapons on LMTS at the reserve center.

Second, the finding that all live rounds fired from LMTS-zeroed weapons during live-fire zero confirmation in Phases 1 and 2 landed within the grid area of the zeroing target also suggests that additional time and ammunition savings are possible. This is because the range firing of live rounds with an LMTS-zeroed weapon is likely to provide the kind of shot location feedback needed to support proper sight adjustments during the zeroing process. Of course, the magnitude of time and ammunition savings to be gained from hitting paper with the first rounds fired will vary directly with the percentage of soldiers that would otherwise fail to do so during live-fire zeroing without the benefit of using an LMTS-zeroed weapon. No data are available on what this percentage might be, but the benefits of LMTS zeroing will be directly proportional to its magnitude.

A number of factors could have contributed to the low zero confirmation rate found for LMTS-zeroed weapons. Convergent evidence suggests that a major factor is the "quality" of the weapon itself. Alignment of the laser transmitter mandrel inside the barrel, for example, may vary (albeit ever so slightly) as a function of weapon manufacturing tolerances, thereby producing an associated bias in laser beam location that cannot be nullified totally by the rotational procedure used to establish a zero aiming point with LMTS. The resulting jump in zero confirmation rate from 0% to 60% that accompanied the switch from rack to match grade weapons in Phase 2, the Phase 3 finding with stabilized rack grade weapons that the LMTS laser beam aiming point did not accurately represent actual bullet strike location, and the impact of individual weapons on laser centroid locations and the distances between laser centroids and shot group centroids, all seem to implicate mandrel alignment as at least a contributing factor to the obtained low zero confirmation rate.

In conclusion, the answer to the question of whether or not an LMTS-zeroed M16A2 rifle can be used for record qualification firing without prior live-fire zero confirmation is "no." Given that LMTS was developed to be a training device and not a zeroing device, its inability to establish a weapon zero that would eliminate the need for subsequent live-fire confirmation was not that surprising. Investigating the device's potential capability to do so was just too important to ignore. We now know this potential does not exist for LMTS as currently designed.

Because the finding that an LMTS-based zero cannot be substituted for a live-fire-based zero in no way undermines the suitability of using LMTS for its intended training purposes, the next step in our research program is to answer a series of questions about LMTS's training-related capabilities as well as its ability to be used as a live-fire performance prediction device. These questions include:

o Can LMTS-based performance be used to identify USAR soldiers in need of sustainment training?

o Can LMTS support effective sustainment training of rifle marksmanship as reflected in improved record fire qualification scores?

o Can live-fire qualification be replaced with LMTS-based qualification when live-fire ranges are unavailable.

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